ASME/ SERAD International Congress
November 2000

RISK MANAGEMENT FOR JET PROPULSION LABORATORY (JPL) FLIGHT PROJECTS

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ABSTRACT

RISK MANAGEMENT IN THE PROGRAM/ PROJECT ENVIRONMENT

The Risk Management process is assuming greater influence in the process of Project and Program Management. The requirements of NPG 7120.5A [NPG, 1998] have created inroads for the results of identifying risk to influence project decisions. Program needs and the interdependencies of risks among projects are receiving increasing attention on major JPL projects. Creating Risk Management plans and requiring risk reporting are beginning to make project personnel aware of the benefit of identifying and mitigating potential future adverse consequences and understanding the trade-offs involved in spending reserves for prevention as opposed to recovery from problems. Risk-based decision-making in the planning phase is allowing risks balancing to be considered, and hard decisions in the cost-capped environment require even reduction in expected mission return in order to provide adequate performance assurance.

RISK ASSESSMENT TOOLS USED IN DESIGN AND ASSURANCE

The paper will describe the use of Risk-revealing checklists and compilations of engineering guidance principles as enabling tools for comprehensive risk identification. Also, effective risk assessment methods (such as Failure Modes Effects Analyses (FMEAs), and Probabilistic Risk Analyses (PRAs) will be discussed. Tracking tools appropriate to maintaining cognizance of risk will be covered.

INTEGRATING RISK AND MANAGING PROJECT RESOURCES

JPL is in the process of identifying a standardized Risk Management methodology, which is based on the two pioneering methodologies developed on the Space Infrared Telescope Facility (SIRTF) and Mars Global Surveyor (MGS) projects. Criteria for assessing risk will be "normalized" with tailoring allowed. Database tools are available now to support this approach for flight projects. The Risk Management team at JPL has developed such a tool, which is in use on many of our projects. An advanced version of the JPL tool has been demonstrated which will provide options for quantitative analysis and resource management trade-offs. Implementation of risk tracking metrics in cost and schedule management systems, and design tools, will allow change to be quickly detected. Also, experience on the MGS project suggests that project management can make effective use of risk impact assessments based on cost, and can therefore gain insight into the effective use of project reserves. Utilizing common risk metrics between the risk management process and design metrics, Problem/ Failure Reports (PFRs), earned value reporting, and other management areas will provide more confidence in the impact of project decisions.

INDEPENDENT ASSESSMENTS AND THE SYSTEMS MANAGEMENT OFFICE (SMO)

The requirement to balance faithful service to the project customer while at the same time provide an objective assessment of the health of the project to the JPL administration and to the agency will be facilitated through the SMO function. Risk Assessments using criteria common to those that the project uses but identification and assessment by independent "eyes" will allow added possibility for early detection and correction of problems. This will enhance the Risk Management effectiveness on the project, and undoubtedly increase the likelihood of mission success.

INTRODUCTION

Risk Management (RM) on Flight Projects at JPL has been evolving over the past few years. The current methodology derives from pioneering efforts on very successful projects of the mid-90's. Project RM is influenced by the evolving relationships among projects and their encompassing programs, and by the requirements of the NASA Procedures and Guidelines for Program and Project Management Processes and Requirements [NPG, 1998], the central guidance for program and project management of flight projects. It is also derived from the practices and tools used by experienced personnel in the "Old Days" (pre-formal RM). This paper explores these influences, and describes the current methodology.

Risk Management has been practiced in a formal way on flight projects beginning with the Mars Pathfinder/ Sojourner project and the Mars Global Surveyor project. The Cassini project, which began development before the establishment of Risk Management as a process at JPL, developed elements of the process (a Risk Management plan and a Risk List), and is implementing Risk Management in the operations phase. The other progenitor of the Risk Management methodology at JPL is the Space Infrared Telescope Facility (SIRTF) project, which is still in the implementation process. The successes realized by these applications of Risk Management have fundamentally shaped our approach to risk identification and assessment. Much of what will be developed in this paper comes from the experiences and lessons learned of these projects. Much of the encouragement to current project managers to utilize Risk Management and specifically the JPL Risk Management process comes from the endorsements of the project managers, review boards, institutional management, and customers of the legacy projects.

Another incentive to implement Risk Management within JPL Flight (and other) projects is the publishing of NPG, 1998. This document has been instantiated into JPL practice through the prime contract between Caltech and NASA to manage JPL. Among other requirements in that document, a Flight Project can have approval to proceed to implementation denied or delayed due to inadequate demonstration of Risk Management planning.

In this paper, then, we will describe the nature of the Risk Management process at JPL, and the degree and variety of Risk Management methods, consistent with the process of NPG, 1998, and reflecting the successful past applications. We will also describe the relationship of Risk Management with other related management and oversight processes, and some areas in which we are working to improve the process.

RISK MANAGEMENT IN THE PROGRAM/ PROJECT ENVIRONMENT

Program and Project Relationship

NPG, 1998 delineates a distinction between programs and projects in each of the agency Enterprises (the four NASA Enterprises are Associate Administrator-level organizations, which together accomplish the NASA strategic objectives). Programs are long-term activities designed to focus on accomplishing each Enterprise's set of the agency's strategic objectives. At JPL, all flight projects are assigned within a program to implement some part of that program's design. In some instances the programs have only one project. In most of the instances where programs contain multiple projects, the relationship between the projects within a program is tenuous, from a strategic objective point of view. The programmatic tie is often a management and budget relationship.

In two programs at JPL, however, strategic relationships are shared among the projects, and these relationships are key elements of program architecture and management. These relationships significantly influence risk assessment and decisions on the individual projects. These programs are actively developing program Risk Management plans, and are identifying risks which are inherent to program objectives, as well as individual project risks. The development of a Risk Management methodology for programs like this is breaking new ground at JPL. The New Millennium Program (NMP) is used here to exemplify the possible influences of program management on project RM. The NMP is a NASA program that moves emerging technologies to an acceptable maturity level for project implementation. These technologies have potentially high payoff for enhancing system performance or enabling missions. The candidate technologies are examined, assessed as to the suitability of flight demonstration and qualification, and grouped in demonstration projects designed to prove their capabilities, and at the same time accomplish some scientific results. The mission requirements on the projects are therefore defined from overall New Millennium program objectives, which are driven by the needs of the Enterprises for those technologies. In the risks identified at the program level are risks associated with the technologies in the technology "catalog." These risks are inherited by the demonstration project that seeks to validate the technology. Also, risks flow outward from the NM projects themselves, through their risk management activity, to the Enterprises' technology "Users."

Figure 1 illustrates these relationships for the New Millennium Program.

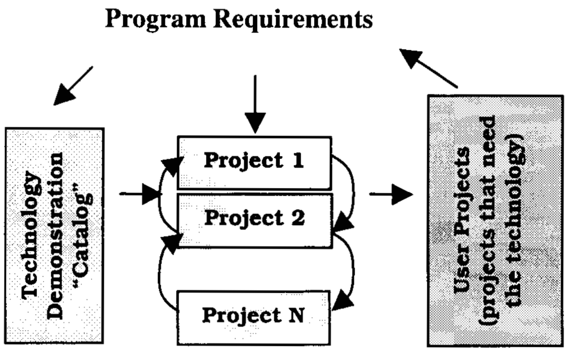

Figure 1 - New Millennium Program Risk Management Risk Relationships between Projects and the Program

The Mars Surveyor Program is also exploring program/ project risk relationship methodology to incorporate highly coupled projects and their own risk assessments into risks assessed at the Program level and assessing the resiliency and robustness of the program architecture against these risks.

Effect on the Project RM Requirements

The methodology chosen by the project for assessing risks, and the criteria by which risks are prioritized, are chosen carefully to accommodate the program/project risk relationships. While RM at the program level is not yet fully understood, the transfer of risks and risk assessments from project to program is an important activity. Section 2 of NPG, 1998 deals with program Risk Management, but is very much based on analogy from project Risk Management, and so does not yet provide much useful insight.

RISK ASSESSMENT TOOLS USED IN DESIGN AND ASSURANCE

In order to provide a degree of comprehensiveness and consistency to the process of risk identification and risk assessment, tools and methods are necessary. Checklists are very helpful tools for identifying risks. At JPL, we have developed and are in continuing to develop checklist-type tools that have great value in the identifying of risks. An example is the ***Design, Verification, Validation, and Operations Principles*** [DVVP, 1998]. These principles were developed within the past two years for the purpose of standardizing and improving the quality of our project development process, and are also ideally suited to guide risk identification and assessment. They represent and document a coordinated set of the wisdom of the senior flight project engineers at JPL, as a reference for less experienced engineers, to transfer, in a sense, experience and insight while they are working on the many projects currently in implementation phase. A short description of the principles follows

Design, Verification, Validation, and Operations Principles

These principles, organized into three categories (General Principles, Detailed Principles, and Flight Operations Principles) are groupings of some 300-odd metrics, wisdoms, guidelines, and methods which have characterized JPL's success in developing and operating missions.

These principles have been created as guidelines to flight project developers. Compliance with the guidelines must be discussed in project planning, and implementation exceptions must be presented at project reviews. They are thus a mechanism for ensuring that the good practices are considered in each project, without being requirements requiring waivers for deviation. They also serve to trigger comprehensive risk considerations.

Figure 2 shows the list of topics in the General Principles.

1. Priorities
2. Develop New Products (DNP)
3. Flight Hardware Logistics Program (FHLP)
4. Mission Data System (MDS)
5. Modeling/ Simulation
6. Make Early Design Decisions
7. Design to Capability/Requirements
8. Risk -Based Design Trade-Offs and Margin
9. Single Failure Tolerance/ Redundancy
10. Nuclear Materials
11. Design Fallback Options
12. Safety and Mission Assurance
13. Design Margins
14. System Performance Allocations
15. Combining Performance Allocations
16. JPL Lessons Learned/NASA Alerts
17. Project Risk Assessments
18. Inheritance
19. COTS/Standards
20. New Concepts/Technology
21. Closed-Loop Failure Reporting
22. Peer Reviews
23. Testability
24. Accessibility
25. Test Beds
26. Test and In-flight Protection of Flight Hardware
27. Systems Validation
28. Design Verification
29. Use of Engineering or Prototype Hardware
30. Critical Hardware Power On/Off Cycling
31. Critical Sequence Telemetry/Monitoring

Figure 2 –General Design, Verification, Validation and Operations Principles

They are written as "shall" statements, but are used to guide projects in considering their approaches to the topic areas. An example follows:

"9. <u>Single Failure Tolerance/ Redundancy</u>

9.1 No credible single failure of any electrical, mechanical or electro-mechanical element shall result in loss of the entire mission.

<u>Note:</u> - Redundancy may be used to provide protection against potential single point failures. Redundancy may be implemented as block or functional redundancy.

9.2 Where block redundancy is used, cross-strapping circuitry shall be subjected to Failure Mode Effects Analysis to demonstrate expected reliability improvements."

In planning, JPL projects are required to address planned deviations from the general principles in the Project Implementation Plan, which the Program manager approves. The project identifies in which reviews the conformance (or deviation) to the detailed principles and the operations principles will be reviewed. This process allows tailoring of the project approach while at the same time providing visibility of potential risks. From a Risk Management point of view then, the planned deviation from the principles trigger risk identification, and the rest of the risk description (impact and likelihood, mitigation possibilities, etc.) data items should be also recorded.

<u>Question for Reviews</u>

Peer Review Questions, is another tool that is being compiled to help make available the expert knowledge of experienced senior JPL technical personnel to the review team members needed for the large number of projects currently in the implementation process.

The large increase in projects has led to having to form review teams with less experienced members, and the questions are a reference source embedded in the JPL Reviews Process which provide guidance to these reviewers. At the same time, the questions are available to designers and technical managers as checklists for good engineering practices and approaches. These then also can be used by the project as checklists to trigger identification of risk areas for consideration in the Risk Management Process.

<u>Mission Assurance Risk Tools</u>

Two risk identification and assessment tools just being introduced into the mission assurance and risk assessment practices at JPL are the ***Defect Detection and Prevention (DDP)*** [DDP, 1998] and the ***Risk Balancing Profiles (RBP)*** [RBP, 2000] tools. These are both tools and methodologies designed to complement each other time-wise in the development of a project. The Risk Balancing Profiles tool is a compilation of best-practices in the disciplines of Mission Assurance – such as Electronic parts programs, reliability engineering applications, environmental testing, SW and HW quality assurance applications, etc. They are compiled in such a way that a planning effort trying to optimize the effectiveness of a limited budget can identify the risks assumed in omitting one assurance task in favor of another. Also, as embodied in the computer mechanization of the tool, the effectiveness of adding mitigating activities can be assessed as to the number of risk areas addressed by the mitigation. This tool provides risk identification only.

The DDP tool provides a more in-depth way of identifying and assessing specific applications of the assurance tasks being planned. QFD (Quality Function Deployment) techniques are used to prioritize the effectiveness of each task in catching risks as a function of the mix of tasks deployed, the characteristics of the system and components designs under investigation, and the importance of the performance or confidence area in question. The ensemble effect of each choice of assurance task combinations can be quickly assessed in terms of residual risk relative to the other combinations assessed, and the relative residual risks.

These two tools are developed in a SW application which links data bases, and allows outputs of the RBP tool to be considered in the DDP tool. In addition to being valuable tools for the Mission Assurance managers at JPL, the tools will have applications in the design areas as trade-off platforms.

<u>Fault/ Failure Protection Design and Analysis Tools</u>

NASA is currently advocating the use of ***Fault Tree Analyses (FTAs), Failure Modes and Effects Analyses (FMEAs), and Probabilistic Risk Assessments (PRAs)*** in a systematic and comprehensive way to assist risk management in identifying, assessing, and making decisions on project risk. JPL has used these tools in well-defined applications consistently for many years, and is expanding their use at the system level to provide consistent insight into all of our projects. FTA has been a standard tool for mechanism reliability analysis, whereas a version of FMEA called Failure Modes and Effects Criticality Analyses (FMECA) has been the method used for electronic assembly reliability analysis. System interface FMECAs are used to assess the systems level robustness to faults in assemblies or black boxes. PRAs are used selectively when design alternatives are considered in an event-driven element of the design. This usually occurs at the system level. Recent examples of this type of analysis are the Mars Pathfinder PRA for the Entry, Descent and Landing (EDL) design, and the much more detailed and exhaustive PRA required to demonstrate and assure the Cassini Earth Flyby success requirement of less than 1×10^{-6} probability of impacting the Earth.

While these applications are effective and appropriate, we are working to augment the use of risk-based methodology to support system and fault protection design. We are developing approaches using integrated systems-level fault tree analysis and subsystem-level FMECAs to provide top-down/ bottom-up views of the system design in all phases of development. This will be a joint systems engineering and reliability engineering activity. One output will be a systematic identification of risks as inputs to the Risk Management process.

Risk Tracking Tools

Tracking tools such as cost and schedule metrics (earned value, milestone tracking, uncertainty analyses); and technical measures (technical resource margins) and risk-rated Problem Failure Reports (PFR) are also part of the risk manager's tool-box.

Earned value is a tool NASA is requiring to be used on all contracted efforts. It allows metrics of degree of work accomplished as planned and within budget, and hence allows regular tracking of expected cost and time to complete. These metrics allow risk magnitudes, and also risk trends, to be assessed.

Technical Performance Measures (TPMs) allow continued tracking of key resources such as available power and data capacity to be tracked. Un-allocated reserves in these resources are risk reducers, and the usage of these reserves and the trend in usage are effective risk tracking metrics. Using the expected levels of reserve (as defined in the Principles described above) for a benchmark, the actual usage comparison metrics will be measures of risk.

INTEGRATING RISK AND MANAGING PROJECT RESOURCES

The current processes in use at JPL for Risk Management are based on methods successfully implemented on two current flight projects. The Mars Global Surveyor project (MGS) is in operational phase at this time- in orbit around Mars. During the development of this project, a risk assessment methodology was used which assessed risk consequences in terms of the impact cost to recover, and identified the most effective mitigation options trading off the risk cost against the cost to mitigate. By appropriately using reserves of dollars, mass, power etc. to mitigate potential in-flight design problems, while tracking the resulting risks to the budget, schedule and technical performance margins, the project pro-actively reduced risk. Risk cost for each risk was measured as the product of likelihood (a numerical probability), and a consequence in terms of dollars. The sum of these risk costs was compared as a soft lien to the budget reserve. By identifying when the risk was most likely to occur, the project could track total risk exposure by Fiscal Year. A simple measure of the resiliency of the project to these risks was calculated by determining the adequacy of the unencumbered reserve in each year (to account for the inevitable unknown random problems that occur). Rules of thumb were established, such that mitigation efforts could be expended in early years to reduce the ratio of risk to reserve in later years. This process was highly regarded in that as long as the current year ratio was reasonably low, dollars could be and were expended to improve the risk robustness of the project. A side benefit was that the initial analysis showed that the planned reserve spread was inordinately back-loaded, and the program office was convinced to redistribute reserve toward the front end to allow for this management strategy to be effected.

The SIRTF process on the other hand is a qualitative process whereby both mission risk and implementation risk are equally weighted in the assessment criteria. Thus a risk whose potential impact could reduce or prevent realization of a major project objective was ranked high, as was a risk which could require most or all of the budget reserves in that system budget to recover from. This specific realization that a flight project needed to address both kinds of risks is a cornerstone of the current JPL Risk Management process. A web-based data entry and tracking tool was developed by the SIRTF project, so that all project elements, geographically spread across the country, could access and use the data. This tool is the core of the generic tool provided for current projects. The generic tool allows for quantitative as well as qualitative criteria to be used. Eventually, trade-offs will be possible using the tool, whereby subsets of mitigation possibilities can be assessed through the net effect on the recovery of resources reserves.

Future Objectives for RM at JPL

JPL is in the process of identifying a standardized Risk Management methodology, which is based on integrating the methodologies of the two pioneering methodologies discussed earlier, and the tools described above. Criteria for assessing risk (likleihood and consequence) will be "normalized", with tailoring allowed. The criteria against which the consequence will be assessed will include any resource considered important for management by the project. In addition to budget (by FY), the possible resources to be used for risk assessment include schedule (critical path and other), workforce, and the TPMs such as spacecraft power, mass, bandwidth, memory, error budgets, processor cycle time, etc. Each risk will be assessed by asking, "what will it take to fix it?" and the impact against each managed resource will be assessed. Using the sum of the products of likleihood and consequence, and techniques of Monte Carlo analysis, estimates of the expected total risk impact on the resources can be developed, as well as the cumulative probability distribution function approximations, which provide some confidence bounds on the estimates. Adding uncertainty estimates to the assessment can further refine these methods.

Similarly, the assessment of Mission Risk through assessing impact against a prioritized set of project success criteria could potentially allow estimation of the expected degree of achievement of success relative to the identified risks in the Significant Risk List. This approach is being studied by our project support team.

Future Goals for the Risk List Tool

Database tools as described above are in use now to support RM for all projects. An Integrated web-based tool will allow input by all project members, configuration control of the maturity of the risk list, and numerical calculations as described for any set of resources the project chooses. Combining quantitative risk aggregating through the use of Monte Carlo techniques enables assessment of the total risk liens on resources, and some measure of the uncertainty of those estimates.

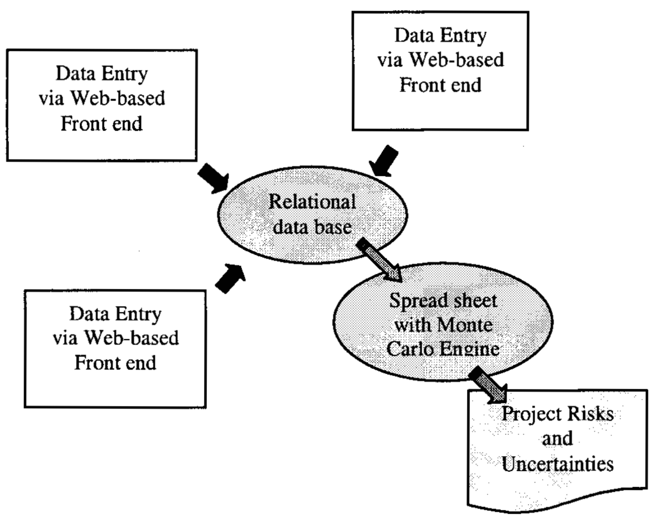

Figure 3 - Web-Based Quantitative Assessment Tool - Page Display

Figure 3 shows a flow of the data developed from inputs provided through the internet from project risk assessors, transferred by the data-base program to a spreadsheet, to which is attached a Monte Carlo engine. Probability Distribution Functions (PDFs) are produced for the expected risk on each resource chosen as a management criteria. These PDFs are plotted against the available reserve for that resource for rapid risk status.

Future Risk Tracking Tools

We are continuing to promote embedding of risk tracking metrics in the institutional project support cost and schedule management systems, and also in the design tools being developed for future projects. These will allow changes in the managed resource margins to be automatically and quickly detected, and incipient risks predicted. Also, experience on the MGS project discussed above demonstrated that project management can make effective use of risk impact assessments based on cost. Therefore extending the technique to look at the other critical project resources could be effective.

Risk as a Common Management Metric

Risk is currently used independently in many of the management systems on a flight project. As an example, the accepted resolution of a problem experienced during the implementation of flight systems is rated as to residual risk in the PFR system. Utilizing common risk metrics between the risk management process, design metrics, PFRs, earned value reporting, and other management areas will provide increased confidence in the "rightness" of project decisions.

INDEPENDENT ASSESSMENTS AND THE SMO

Flight Projects need to review their effort and accomplishment on a regular basis, focusing on the areas of most concern to the project. Project-percieved risk is an important element of that review. There is an additional requirement to balance project risk assessment with the provision of an objective "independent" assessment of the health of the project to the JPL administration and to the customer. This latter function will be facilitated through the Systems Management Office (SMO). This Office acts within JPL in a manner similar to the actions of the NASA Independent Assessment Office at Langley Research Center. Teams of key reviewers will be tasked to examine a project at critical points, sometimes through in-depth peer reviews, and sometimes in conjunction with natural milestones such as the Preliminary Design Review or the Critical Design Review. Risk assessments using criteria common to those that the project uses but identified and assessed by independent "eyes" will allow added possibility for early detection and correction of problems, and can calibrate the thoroughness of the project risk management process. Risk will be a major metric for assessing overall project adherence to plan, enabling the JPL Management to make effective assessments to the NASA customer. This process is called for in the NASA management requirements document NPG, 1998. The objective is to identify early non-viable projects in this Better-Faster-Cheaper environment, and will enhance the Risk Management effectiveness on the project. All of these efforts are designed to ultimately increase the likelihood of mission success.

CONCLUSION

Risk Management at JPL is continuing to mature and be accepted as an integral methodology for Project Managers. The importance of risk dependence between project and programs is being addressed and accounted for in the JPL Risk Management process. NASA guidance, through the program and project management guidelines, has been significant in focusing attention toward the effectiveness of Risk Management. New tools are being used effectively in all elements of risk management – risk identification and assessment, decision-making, and risk tracking. Also, the Risk Management methodology being used by the projects at JPL is also improving the independent assessment capability of the Laboratory and NASA. Overall, this evolving and maturing process at JPL is gaining universal acceptance in our flight projects, and the experience and feed-back from these projects result in improved tools and guidance for the next projects in the pipeline. We must continue to share experiences with centers and institutions with similar activities, and so ensure our sustained success in space flight endeavors.

Acknowledgement

The work described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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